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Research Article

Can different sowing dates affect weed control efficacy and chickpea yield?

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Abstract: Two independent field experiments were carried out on two sowing dates. The experimental factors included three herbicides (trifluralin, pendimethalin, and linuron) using the method of incorporation by sowing, inter-row cultivation, and control (weed-free and weed-infested). The density of weeds 45 days after sowing, applying pendimethalin, linuron, and inter-row cultivation on the first sowing date (FSD), was 26.5, 31.8, and 45.9% less than the second sowing date (SSD), respectively. On the contrary, at the flowering stage, weeds on the SSD were 59% less than the FSD, and the average weed density in applying pendimethalin and linuron was 78.7% less than their density in the weed-infested. The height of the plant and the height of the first pod from the soil surface on the FSD were 13% and 11% higher, respectively, compared to the SSD. The average number of branches per plant with experimental treatments was 37% more than the weed-infested ones. The maximum biological yield of chickpeas in the FSD and SSD was obtained by inter-row cultivation (760 g m^{-2}) and pendimethalin (749 g m^{-2}), respectively. On the FSD, the seed yield in applying pendimethalin was 82.5%, and its average in linuron and inter-row cultivation was 86.4% more than the weed-infested control. Also, on the SSD, the average seed yield in the three mentioned treatments was 73.6% more than the weed-infested control. However, linuron and inter-row cultivation were identified as the most appropriate treatments for weed control in the early stages of both sowing dates.

Keywords: Incorporation, inter-row cultivation, linuron, pendimethalin, sowing date

Introduction

Chickpea *Cicer arietinum* L. is one of the critical crops of the legume family (Fabaceae), which is considered the primary alternative for providing protein and minerals required by humans all over the world, especially in developing countries (Nezami *et al*., 2022). Furthermore, chickpea plays an influential role in nitrogen fixation, soil fertility, and livestock feeding (Jukanti *et al*., 2012). Chickpea production globally has reached 15.1 MT, among which Asian countries rank first, producing 87% of world production (FAOSTAT, 2020). The production of 78% of

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this product by low-income and food-deficient countries indicates its unique role as an alternative source of animal protein and a suitable option for ensuring food security (FAOSTAT, 2020). In Iran, chickpea has taken first place among legumes, with a harvest level of about 70% (Agricultural Statistics, 2020).

Weeds are one of the limiting factors for achieving high yield in chickpeas. They use nutrients and moisture in the soil and compete with crops (Kanatas and Gazoulis, 2022). The slow-growing nature of chickpeas makes them more vulnerable to weeds, especially when infested with broadleaf weeds (Rastgoo *et al*., 2022; Taran *et al*., 2013). Yield decrease in chickpeas may vary from 24% to 63%, depending on the level of weed infestation (Muhammad *et al*., 2011). In addition, weeds can be considered as alternative hosts for important pests, especially in reduced tillage systems (Hayden *et al*., 2012).

Spring sowing of chickpeas is common in temperate and cold regions of Iran due to the lack of exposure to freezing stress (Nezami *et al*., 2023). It seems that it is necessary to find a suitable sowing dateto increase the benefit of March rains and the efficacy of weed control methods. Chemical control of weeds is an effective method to achieve high crop yield and productivity. Many studies indicate herbicides reduce weeds'density and increase the seedyield in legumes such as chickpeas. In the meantime, pre-emergent herbicides such as trifluralin and aclonifen were recommended to control weeds of chickpeas. However, these herbicides cannot control a wide range of weeds. Some post-emergence herbicides (such as quizalofop-p-ethyl) only control narrow-leaf weeds in pea fields (Kumar *et al*., 2015). On the other hand, the inefficiency and lack of economic justification for the use of lentagran and manual weeding due to the limitation of the labor force in the critical period for weed control of chickpeas (30 to 60 days after the emergence of the crop), reveals the need to introduce appropriate methods for efficient control of weeds in spring chickpea, more than before (Singh *et al*., 2014).

Sowing date, composition, and species frequency determine chickpea weeds' relative time of emergence and establishment. Hence, it is necessary to decide onthe density and efficacy of weed control methods in chickpea fields in the expected sowing dates of this plant. The current study compares chickpeas'weed density, yield, and yield-related variables in response to two spring sowing dates and applying pre-planting herbicides mixed with soil and inter-row cultivation.

Materials and Methods

Site description and procedure

This study was conducted at the research farm (59˚23′ E, 36˚15′ N) of Ferdowsi University of Mashhad (FUM), Iran. The chickpea seed (MCC797) was obtained from the Mashhad chickpea collection of FUM. Soil preparation was conducted using a moldboard plow followed by a cyclotiller. Seeds of chickpeas were hand-sown by a distance of 2 cm in 3 cm soil depth and six rows 55 cm apart and six meters long in plots. The characteristics of experimental soil are presented in Table 1.

Experimental treatments

The trial was conducted in a split-plot arrangement of a randomized complete block design with three replications. The main plots consisted of two sowing dates (March 1 and 15, 2022), while the subplots included five experimental factors.The factors of this experiment include:1) trifluralin (Treflan®, 48% EC, 2 L ha^{-1}), 2) pendimethalin (Stomp®, 33% EC, 3.5 L ha^{-1}), 3) linuron (Afhalen®, 45% SC, 2 L ha^{-1}), 4) inter-row cultivation (using rota-cultivator), 5) control (weed-free and weed-infested).

Table 1 The characteristics of soil samples were examined.

Texture class	pH	EC (dS m^{-1})	O. M (%)	N (%)	P (mg kg^{-1})	K (mg kg^{-1})
Silt loam	7.34	2.38	0.64	0.068	16.83	112

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Herbicides were pre-planting for application "as an incorporated by sowing" (IBS) treatment in chickpeas.

Application of treatments

On both sowing dates, herbicides were applied using a rechargeable backpack sprayer equipped with a TeeJet nozzle and an output volume of 250 L ha^{-1} at a pressure of 260 kPa. Herbicides (IBS) were applied in wet soil fields (Croser *et al*., 2021). In this method, the herbicide is used first, thenthe seed drill machine sows chickpeas. Chickpea seed is not placed in the place impregnated with herbicide to protect from damage. Inter-row cultivation was implemented 30 days after chickpea emergence on both sowing dates. The complete hand weeding was done during the growing season in weed-free plots. Irrigation was conducted three times during the growth period: immediately after sowing, two weeks after the first irrigation, and during the flowering stage.

Sampling and evaluation of traits

During the growing season, monitoring and sampling of the weed population of the field were done to determine their density and composition. The density and biomass of weeds (using a 70 °C oven for 72 hours) by species in different treatments in three stages, including 45 days after sowing (DAS), flowering, and podding stage using a quadrat ($1m^2$), were investigated.

At the end of the cropping season, yield-related variables, including plant height, the lowest pod height from the soil surface, the number of primary branches, the plant weight, the number of pods per plant, the number of seeds per pod, the weight of seeds per plant, and the 100- seed weight were evaluated. Seed yield (SY) and biological yield (BY) were obtained by removing the marginal effects and harvesting the plants of the middle four rows, as well as the harvest index (HI) by calculating.$\frac{SY}{BY}\times100$.

Statistical Analysis

Before the analysis of variance (ANOVA), data were subjected to the normality test using the Shapiro-Wilk test. Data were analyzed using the SAS 9.4 software (*v*. 9.4, SAS Institute Inc, Cary, NC, USA), and means were separated using LSD at $P = 0.05$. Graphs were drawn by GraphPad Prism ver 8.0.1 software (*v*. 8.0.1, La Jolla, CA. USA).

Results

Composition and frequency of species

The composition and frequency of weed species were different in two chickpea sowing dates (Table 2). On the first sowing date (FSD), prostrate knotweed *Polygonum aviculare* L. and common fumitory (*Fumaria officinalis* L.) with a total of 78.2%, and on the SSD, common fumitory, lambsquarters *Chenopodium album* L., prostrate knotweed and black nightshade *Solanum nigrum* L. with a total of 78.3% accounted for the highest relative frequency. The relative frequency of annual broadleaf weeds on chickpeas' first and second sowing dates was 97% and 98%, respectively. On the first and second sowing dates, 95.7% and 90.3% of weed species had a C_3 photosynthetic pathway (Table 2).

Density and biomass of weeds under experimental treatments

Weed density and biomass 45 DAS were significantly different in the two chickpea sowing dates and experimental treatments (Table 3 and Fig. 1, A). In this way, the density of weeds in applying pendimethalin, linuron, and inter-row cultivation on the FSD was 26.5%, 31.8%, and 45.9% less than on the second, respectively. On the first and second sowing dates, weed density in the application of pendimethalin was 57.1 and 48.7%; in linuron, it was 79.2% and 73.3%; and in inter-row cultivation, it was 83.4% and 70.7% was less compared to control (weed-infested). Weed biomass at the mentioned time (45 DAS) in the application of pendimethalin, linuron, and inter-row cultivation on the FSD was 40.5%, 38.1%, and 40.2% less than the SSD (Table 3 and Fig. 1, B).

Table 2 Relative frequency and other characteristics of prominent weeds in the field at two sowing times.

Common names	Latin names	Family	Growth form	Photosynthetic pathway	Relative frequency (%)	
					1st sowing date	2nd sowing date
African Mustard	*Malcolmia africana* L.	Brassicaceae	ABL	C_3	1.43	-
Amaranthus	*Amaranthus* spp.	Amaranthaceae	ABL	C_4	1.75	8.06
Black nightshade	*Solanum nigrum* L.	Solanaceae	ABL	C_3	6.37	12.5
Common barnyardgrass	*Echinochloa crus-galli* (L.) P. Beauv.	Poaceae	AG	C_4	1.43	1.21
Common cocklebur	*Xanthium strumarium* L.	Asteraceae	ABL	C_3	2.39	5.24
Common fumitory	*Fumaria officinalis* L.	Papaveraceae	ABL	C_3	16.34	35.10
Curled dock	*Rumex crispus* L.	Polygonaceae	PBL	C_3	0.50	-
Field bindweed	*Convolvulus arvensis* L.	Convolvulaceae	PBL	C_3	0.50	0.80
Flixweed	*Descurainia sophia* L.	Brassicaceae	ABL	C_3	0.64	-
Jimsonweed	*Datura stramonium* L.	Solanaceae	ABL	C_3	2.39	5.24
Lambsquarters	*Chenopodium album* L.	Amaranthaceae	ABL	C_3	2.23	16.13
Prostrate knotweed	*Polygonum aviculare* L.	Polygonaceae	ABL	C_3	61.89	14.52
Purple nutsedge	*Cyperus rotundus* L.	Cyperaceae	PS	C_4	0.64	-
Purslane	*Portulaca oleracea* L.	Portulacaceae	ABL	C_4	0.50	0.40
Sowthistle	*Sonchus* spp.	Asteraceae	ABL	C_3	0.50	0.40
Venice mallow	*Hibiscus trionum* L.	Malvaceae	ABL	C_3	0.50	0.40
Species frequency (%)						
C_3					95.68	90.33
C_4					4.32	9.67
Narrow leaf + Sedge					2.07	1.21
Broad leaf					97.93	98.79

ABL: Annual Broadleaf; *AG*: Annual Grass; *PBL*: Perennial Broadleaf; *PS*: Perennial Sedge.

Table 3 The effects of sowing date and treatment on weed density and weed biomass.All analyses were performed at a significance level of $a = 0.05$.

S. O. V	Df	Weed density			Weed biomass		
		45 days after herbicide application	Flowering stage	Podding stage	45 days after herbicide application	Flowering stage	Podding stage
Block	2	*	**	ns	**	ns	ns
Sowing date (SD)	1	**	**	**	**	**	ns
Ea	2						
Treatment (T)	5	**	**	**	**	**	**
SD × T	5	**	ns	**	*	**	**
Eb	20						
CV %		7.8	23.2	29.3	14.2	34	25.3

*, **, ns: $p \leq 0.05$, $p \leq 0.01$, $p \geq 0.05$ (non significant), respectively.

The main effects of sowing date and treatment on weed density in the flowering stage were significant (Table 3). Weed density on the SSD was 59% lower than on the first (Fig. 1, C). Weed density in pendimethalin and linuron was 79.9% and 77.3% less than the weed density in weed-infested control (Fig. 1, C). The weed biomass in the flowering stage in applying trifluralin, pendimethalin, linuron, and inter-row cultivation on the SSD was 84.5%, 96%, 100% and 61.4% less than the FSD, respectively (Fig. 1, D).

Weed density in the podding stage in applying pendimethalin and inter-row cultivation on the SSD was 75% and 100% lower than the FSD, respectively (Table 3 and Fig. 1, E).

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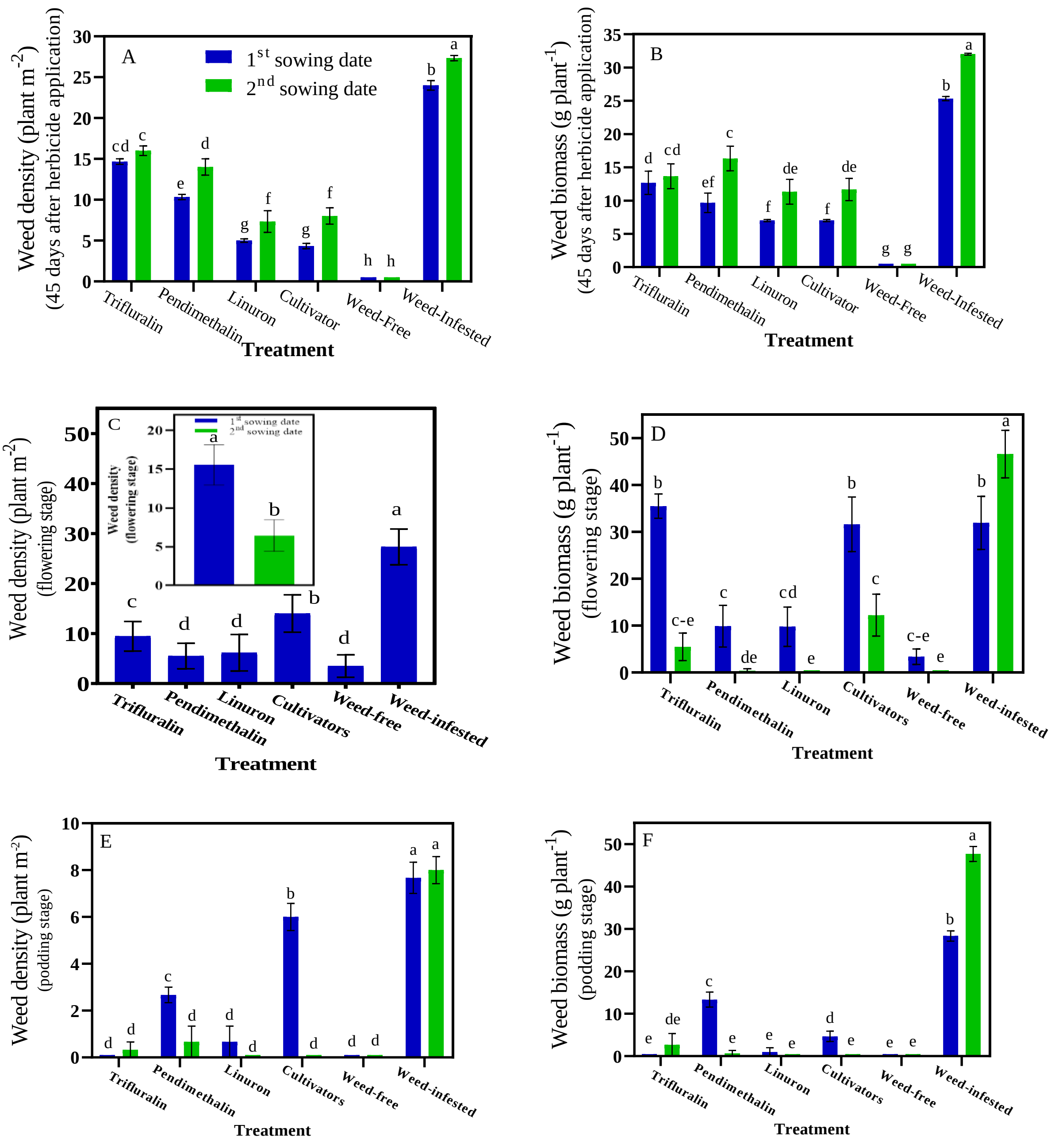

Figure 1 The effects of sowing date and treatments on weed density and weed biomass in three sampling times. Error bars represent standard error of the mean. Different letters in the bar labels indicate significant differences between the sowing date and treatments.

On the first and second sowing dates, weed density in the use of trifluralin was 100% and 96%; in pendimethalin, 65.2% and 91.6%; in linuron, 91% and 100%; and in inter-row cultivation, 22% and 100 %, was less than the weed-infested control. The highest weed biomass belonged to the FSD and the experimental treatments of pendimethalin and inter-row cultivation (Table 3 and Fig. 1, F). However, on the FSD, the biomass of weeds

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using pendimethalin and inter-row cultivation decreased by 53% and 83.5%, respectively, compared to the weed-infested control.

Chickpea yield-related variables

The plant height, the lowest pod height, and the number of branches in the plant on the FSD were 13%, 11%, and 17% higher, respectively, compared to the SSD (Tables 4 and 5). According to Table 6, the average number of branches per plant was 37% more than the weed-infested control under the influence of the experimental treatments. The plant's dry weight in applying pendimethalin, linuron, and inter-row cultivation was statistically in the same group as the weed-free (Table 6). On average, the dry weight of the plant in the mentioned treatments was 63.5% more than the weed-infested control (Table 6).

The interaction between the sowing date and treatments on the number of pods per plant was significant (Table 4). Pendimethalin application and inter-row cultivation on the FSD were in the same statistical group as weed-free (Table 7). The average number of pods in the two mentioned treatments was 80.7% more than the weed-infested control.On the SSD, application of linuron and inter row cultivation resulted in the same statistical group as weed-free (Table 7). The average number of pods in the two mentioned treatments was 65.9% more than the weed-infested control.

On the FSD, the highest seed weight per plant belonged to the weed-free treatment (Table 7). Next to that, applying pendimethalin and inter-row cultivation led to an increase of 97.7 and 97% in seed weight per plant compared to the weed-infested control. On the SSD, linuron and inter-row cultivation with the weed-free were in a similar statistical group. The average seed weight in these treatments was 93.1% more than the weed-infested control (Table 7).

On the FSD, the 100-seed weight due to linuron and inter-row cultivation was included in a similar statistical group with weed-free (Table 7). The average 100-seed weight in the two mentioned treatments was 29% more than the weed-infested control. On the SSD, the 100-seed weight in the applied treatments and the controls (weed-free and weed-infested) were in a similar statistical group.

Biological yield and seed yield of chickpea

On the FSD, inter-row cultivation was recognized as the most suitable treatment regarding the biological yield of chickpeas (Tables 4 and 7). So, in this method, the biological yield of chickpeas was 68.2% higher than the weed-infested control.However, the biological yield in the mentioned treatment was 18.4% lower compared to the weed-free control. On the SSD, the most suitable treatment was pendimethalin, which was in the same statistical group with weed-free control and had 71% more biological yield than the weed-infested control (Table 7).

Table 4 The effects of sowing date and treatment on yield and yield-related variables. All analyses were performed at a significance level of *a* = 0.05.

Source of variation	Df	Plant height	Lowest pod height	Branch No. p^{-1}	Plant weight p^{-1}	Pod No. p^{-1}	Seed No. pod^{-1}	Seed weight p^{-1}	100- seed weight	Biological yield	Seed yield	Harvest Index
Block	2	ns	ns	ns	ns	ns	ns	*	ns	ns	**	**
Sowing date (SD)	1	**	*	*	ns	**	ns	**	ns	**	**	**
Ea	2	-										
Treatment (T)	5	ns	ns	*	**	**	ns	**	*	**	**	**
SD × T	5	ns	ns	ns	ns	**	ns	**	*	**	**	ns
Eb	20	-										
CV %		11.7	14.9	20.8	28.1	30	30	28.9	9.5	20	18	29.8

*, **, ns: $p \leq 0.05$, $p \leq 0.01$, $p \geq 0.05$ (non significant), respectively.

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Table 5 The effects of sowing date on plant height, lowest pod height, and harvest index.

Sowing date	Plant height (cm)	± SE	Lowest pod height (cm)	± SE	Branch No.(p^{-1})	± SE	Harvest Index (%)	± SE
1st sowing date	52.54^{a}	1.34	27.85^{a}	1.12	5.81^{a}	0.31	13.52^{a}	1.23
2nd sowing date	45.72^{b}	1.69	24.82^{b}	0.92	4.80^{b}	0.32	8.25^{b}	1.28

Means with different letters in each column are significantly different based on the LSD test at $p \le 0.05$.

Table 6 The effects of treatments on branch No., plant weight, and harvest.

Treatment	Branch No. (p^{-1})	± SE	Plant weight (p^{-1})	± SE	Harvest Index (%)	± SE
Trifluralin	5.56^{a}	0.39	30.84^{b}	5.15	7.71^{cd}	1.44
Pendimethalin	5.61^{a}	0.47	41.67^{ab}	4.84	11.02^{bc}	2.55
Linuron	5.78^{a}	0.53	40.61^{ab}	6.70	15.12^{a}	2.26
Cultivator	5.50^{a}	0.65	48.28^{a}	4.06	11.71^{ab}	1.84
Weed-Free	5.83^{a}	0.63	47.11^{a}	2.89	13.94^{ab}	2.20
Weed-Infested	3.56^{b}	0.40	15.89^{c}	3.19	5.83^{d}	2.40

Means with at least one similar letter in each column are not significantly different based on the LSD test at $p \le 0.05$.

Table 7 The effects of sowing date and treatments on pod no.,seed weight, 100-seed weight, and biological yield.

Sowing date	Treatment	Pod No. (p^{-1})	± SE	Seed weight (p^{-1})	± SE	100-seed weight (g)	±SE	Biological yield (g m^{-2})	±SE
1st sowing date	Trifluralin	58.6^{cd}	13.8	5.6^{de}	1.4	32.7^{ab}	1.2	276.4^{ef}	57.6
	Pendimethalin	90.3^{ab}	7.7	13.2^{b}	1.1	28.1^{b-d}	1.6	470.5^{cd}	62.9
	Linuron	41.0^{de}	9.3	7.3^{cd}	2.7	30.8^{a-c}	1.1	541.7^{cd}	19.0
	Cultivator	75.4^{a-c}	6.4	10.2^{b}	1.4	32.9^{a}	0.4	759.9^{b}	19.1
	Weed-Free	94.7^{a}	6.2	17.0^{a}	1.0	29.7^{a-d}	1.9	931.6^{a}	74.6
	Weed-Infested	16.0^{e}	6.3	0.3^{f}	0.1	22.6^{e}	2.0	241.7^{f}	56.0
2nd sowing date	Trifluralin	28.3^{e}	10.3	1.7^{f}	1.2	27.1^{c-e}	1.2	236.3^{f}	59.2
	Pendimethalin	36.9^{de}	9.5	2.5^{ef}	1.0	26.0^{de}	2.0	749.2^{b}	42.4
	Linuron	63.0^{b-d}	7.3	8.1^{cd}	1.4	28.3^{a-d}	0.9	410.7^{de}	80.5
	Cultivator	60.2^{cd}	8.4	9.4^{c}	0.8	29.6^{a-d}	2.6	377.0^{d-f}	47.7
	Weed-Free	59.7^{cd}	7.8	8.8^{cd}	1.6	29.1^{a-d}	1.7	628.4^{bc}	88.5
	Weed-Infested	21.0^{e}	8.8	0.6^{f}	0.5	29.1^{a-d}	1.1	219.3^{f}	30.4

Means with at least one similar letter in each column are not significantly different based on the LSD test at $p \le 0.05$.

Seed yield on the FSD compared to the second was significantly higher in pendimethalin, linuron, and inter-row cultivation treatments (Table 4 and Fig. 2). On the other hand, the seed yield in pendimethalin was 82.5%, and the average seed yield in the application of linuron and inter-row cultivation was 86.4% more than the weed-infested control. However, this value was 41% less in linuron and inter-row cultivation and 54.6% in pendimethalin compared to the weed-free control (Fig. 2). On the SSD, the effect of pendimethalin, linuron, and inter-row cultivation on seed yield was in a similar statistical group with weed-free control (Fig. 2). The average seed yield in the three mentioned treatments was 73.6% more than the weed-infested control. Furthermore, applying trifluralin on both sowing dates had a similar effect on seed yield and was placed in a similar statistical group with the weed-infested control (Fig. 2).

The harvest index on the FSD was 39% higher than on the SSD (Tables 4 and 5). The application of linuron and cultivator treatment with weed-free control were in a similar statistical group (Table 6). The average harvest index in linuron and inter-row cultivation was 56.5% higher than the weed-infested control.

According to the results of linear regression analysis, the relationship between seed yield and weed density 45 DAS on both the first (R^2 = 0.87^{***}) and second (R^2 = 0.79^{*}) sowing dates is negative and significant (Fig. 3).

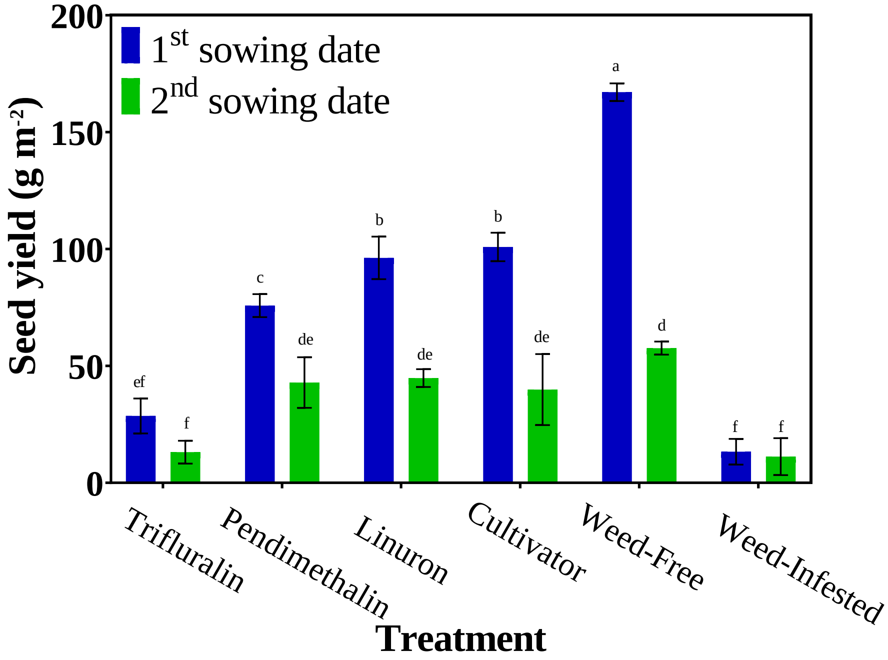

Figure 2 The effects of sowing date and treatments on chickpea seed yield.
Error bars represent standard error of the mean. Different letters in the bar labels indicate significant differences between the sowing date and treatments.

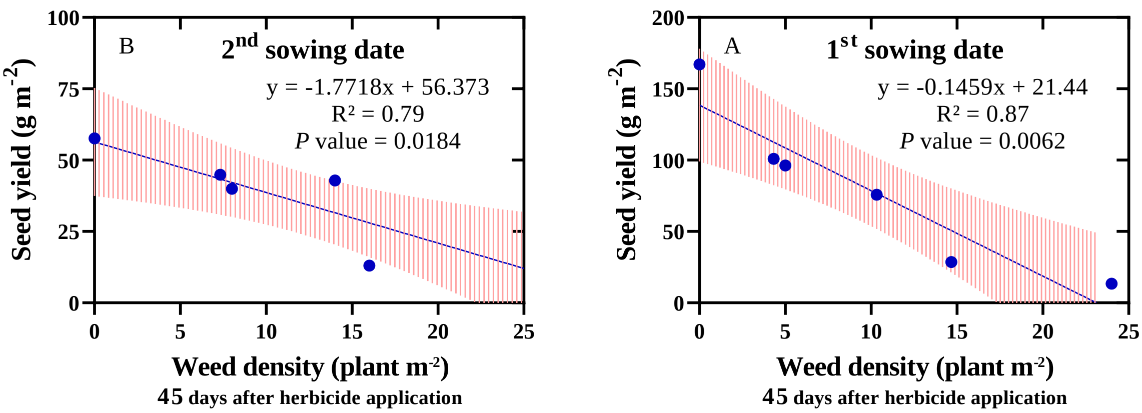

Figure 3 Linear regression analyses between chickpea seed yield data and weed density data.
Dashed lines represent the 95% confidence interval of the fitted line.

Discussion

The relative abundance of narrow-leaved and broad-leaved weeds was almost the same on both sowing dates (Table 2); therefore, the morphology of the species did not have an influential role in the difference in the efficacy of herbicides (45 DAS). Since the herbicides were used by the IBS method, the probability of their being affected by temperature was also low (Hasanfard *et al*., 2022; Hasanfard *et al*., 2023). Therefore, the difference in the composition of weed species between the

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two sowing dates was one of the possible causes for the variation in the efficacy of chemical control. Such that, pendimethalin and linuron were more effective in controlling the dominant weeds (prostrate knotweed and common fumitory) on the FSD.In the monitoring of weeds 45 DAS, the lower efficacy of inter-row cultivation on the SSD is probably related to the more suitable temperature conditions for the germination and re-emergence of weeds from the time of inter-row cultivation to the evaluation of the density of weeds (about ten days). In other words, the re-emergence of weeds in the third ten days of April was more compared to the beginning of April. The same issue has made implementing a cultivator on the SSD less effective. Nath *et al*. (2021) reported in a similar experiment that the application of pendimethalin - quizalofop-p-ethyl was highly effective in controlling weeds of chickpeas. These researchers reported the herbicide's efficacy in weed control 45 DAS to be more than 95 DAS. In general, the pre-emergence application of pendimethalin in chickpeas has been recommended by some researchers (Sondhia, 2012; Ahmad *et al*., 2016). Pendimethalin is a systemic herbicide that is absorbed through the roots and leaves and controls the weed quickly after germination or emergence (Ahmad *et al*., 2016). In a study, it has been observed that among the weed control treatments, the use of pendimethalin with 0.75 and 1 kg h^{-1} had the highest net return in economic terms and the ratio of profit to cost in the chickpea field (Buttar *et al*., 2008).

In the flowering and pod formation stage, the density and biomass of weeds on the FSD were higher than in the second. The growth of weed species during the cropping season was probably more due to the decrease in the efficacy of the treatments used on the FSD (earlier treatment application date). Also, the extended growth period in the FSD has probably led to more weed biomass (in the flowering and podding stages) compared to the second.

The more extended growth period was probably one of the reasons for the superior morphological characteristics of chickpeas on the FSD (earlier sowing) compared to the second. The use of pendimethalin is known as one of the effective treatments for the dry weight of chickpeas. Similarly, it has been reported that applying the mentioned herbicide has led to a 10% increase in the dry weight of a chickpea plant compared to the weed-infested control (Nath *et al*., 2021). Contrary to the results of this experiment, Akhter *et al*. (2021) reported the delay in sowing wheat *Triticum aestivum* L. as one of the appropriate management strategies to control some weed species. Although, in the present experiment, the application of treatments on two sowing dates had different effects on the density and biomass of weeds, considering the significant reduction of these traits, the reduction of competition can be the primary reason for the improvement of chickpea yield components under the effect of weeds' control.

The number of chickpea branches is often directly related to seed yield (Vaghela *et al*., 2009). Therefore, by reducing the density and biomass of weeds, the applied treatments provided suitable space and competitive conditions for increasing the number of branches in chickpeas. For this reason, one of the main reasons for the increase in chickpea yield due to the use of experimental treatments was the increase in the number of its branches due to the control of weeds.

Weed control leads to increased access to light, water, and nutrients by the crop (McErlich and Boydston, 2014) and subsequently to an increase in leaf area, an increase in the production capacity of the photosynthetic products and their translocation, and an increase in chickpea yield components. In this experiment, the biological yield was more related to the yield components (number of pods, seed weight, and 100 seed weight) on the FSD.

The growth of chickpeas is inherently slow, and this issue leads to a delay in the closing of its canopy. As a result, the surface of the soil is exposed to light for a long time, and weeds also germinate and establish in the field; therefore, the implementation of any efficient control practices in the chickpea field, especially in the initial stages of growth, can reduce the growth of weeds. Also, closing the canopy of chickpeas in the early stages of the growing season will lead to its greater competitiveness in other stages. In the present experiment, the higher seed yield on the FSD compared to the second was the lower density and lower biomass of weeds 45 DAS (Fig. 1, A and B). In other words, in the critical period of weed control, their density and biomass were less with experimental treatments. The same issue was the reason for the success of chickpea seedlings in increasing the leaf area, production, and translocation of photosynthesis products. Researchers reported that chickpea seed yield reduced by 17.1% during the first 30 days of sowing due to weed competition, and this reduction increased to about 50% in the entire cropping season (Singh and Singh, 1992). The post-emergence application of pendimethalin - quizalofop-p-ethyl (45 and 95 DAS) led to a 51% increase in chickpea yield (Nath *et al*., 2021). Hence, its post-emergence application in the critical period of weed control in combination with other methods (mechanical and chemical) is also suggested. Late-emerging weeds can significantly reduce chickpea yield (Yenish, 2007); therefore, it is predicted that if there were additional treatment(s) in the current experiment, the seed yield of chickpeas might increase even more. It has been reported that the pre-emergence application of pendimethalin and manual weeding 30 and 60 DAS significantly reduced the density and biomass of weeds and led to the production of the highest yield of chickpea seeds (Nepali *et al*., 2022).

The critical fact in this experiment was the low efficacy of trifluralin as a recommended pre-planting herbicide compared to other practices. Despite this herbicide's relative control of weeds, chickpea yield and most of its related characteristics, including biological yield, were not significantly different from the weed-infested control in both sowing dates (Table 7 and Fig. 2). In other words, its application made no difference to the non-control of weeds. Trifluralin (from the chemical family of dinitroaniline) inhibits cell division and is considered among soil's relatively immobile and stable herbicides (Wallace, 2014). According to objective observations in the field, the growth rate of chickpea seedlings (especially in the early stages of growth) was less in the trifluralin treatment than in other treatments (Fig. 4). This issue caused a competitive environment for weeds in the following stages. In addition, the delay in the emergence and other phenological stages caused a significant decrease in the biological yield and seed yield as affected by this herbicide. The sensitivity of chickpeas to trifluralin was probably higher than other tried herbicides, and despite its use with the IBS method, it has been more affected.

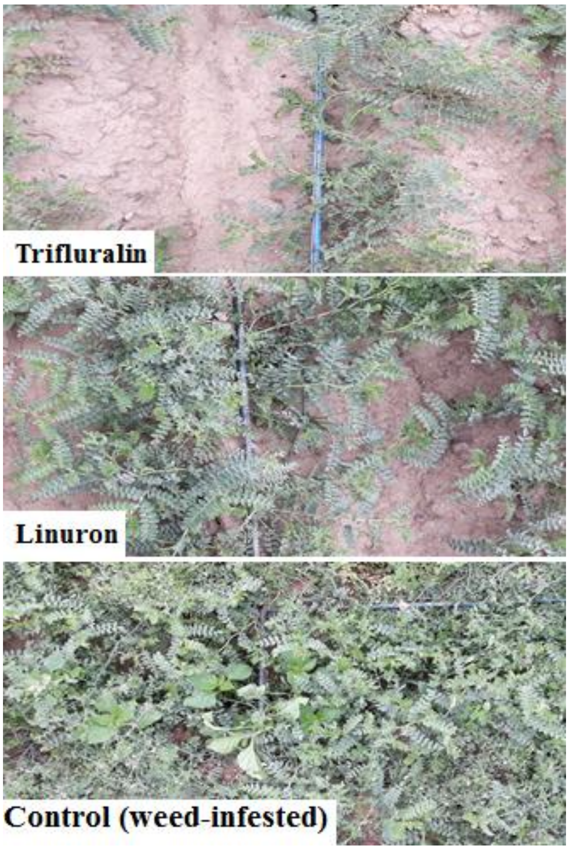

Figure 4 The difference in the size of chickpea seedlings and canopy conditions in the suitable and the unsuitable herbicide treatments and the (control) weed-infested at the same time (mid-May).

A significant decrease trend between seed yield and weed density in the early stages of growth proved that adopting appropriate methods and, therefore, less weed density in chickpeas' critical period of weed control will result in a further increase in seed yield. A negative and significant linear regression was observed in a similar experiment between weed density and chickpea yield (Kanatas and Gazoulis, 2022).

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Conclusion

The weed population dynamics in different sowing dates and ecological conditions are variable. Therefore, in this experiment, the difference in the efficacy of weed control practices in two chickpea sowing dates was expected.In both sowing dates, about 98% of weed species were broadleaf. Thus, two herbicides, pendimethalin and linuron, showed promising efficacy in controlling broadleaf species. The most appropriate treatment on the FSD (March 1) and the second (March 15) regarding weed control in the early stages and chickpea seed yield was linuron and inter-row cultivation.In the present experiment, weed control methods on the FSD were more effective. One of the possible reasons for the high efficacy of weed control methods on the FSD compared to the second was the difference in the frequency and composition of weed species. Regardless of the efficacy of weed control methods, earlier sowing of chickpeas due to the length of the vegetation period and the closure of the canopy, has indirectly led to high competitiveness and, as a result, increased yield of chickpeas. On the other hand, the IBS method is recommended as a suitable approach in optimizing soil-applied herbicides (especially pendimethalin and linuron) and not damaging the plant in chickpea fields.Integrating the experimental treatments with another treatment will significantly increase weed control and chickpea seed yield. Considering the high efficacy of inter-row cultivation in this experiment and environmental concerns, it is suggested that linuron and pendimethalin be used in a reduced dose and integration with the inter-row cultivation.

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Conflict of interest

The authors declare that they have no conflict of interest.

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آیا تاریخ کاشت می‌تواند بر کارایی کنترل علف‌های هرز و عملکرد نخود تأثیرگذار باشد؟

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چکیده: دو آزمایش مزرعه‌ای به‌طور مجزا در دو تاریخ کاشت توسط سه علف‌کش (تریفلورالین، پندی‌متالین و لینورون) با روش اختلاط هم‌زمان با کاشت (IBS: Incorporation by Sowing)، عملیات کولتیواتور ۳۰ روز پس از سبز شدن نخود، وجین کامل و عدم وجین علف‌های هرز انجام شد. تراکم علف‌های هرز ۴۵ روز پس از کاشت، در کاربرد پندی‌متالین، لینورون و عملیات کولتیواتور در تاریخ کاشت اول به‌ترتیب ۲۶/۵، ۳۱/۸ و ۴۵/۹ درصد کم‌تر از تاریخ کاشت دوم بود. برعکس، در مرحله گلدهی تراکم علف‌های هرز در تاریخ کاشت دوم ۵۹ درصد کم‌تر از تاریخ کاشت اول بود و میانگین تراکم علف‌های هرز در کاربرد پندی‌متالین و لینورون ۷۸/۷ درصد کم‌تر از تراکم آن‌ها در شاهد آلوده بود. ارتفاع بوته و ارتفاع اولین غلاف از سطح خاک در تاریخ کاشت اول به‌ترتیب ۱۳ و ۱۱ درصد در مقایسه با تاریخ کاشت دوم بیش‌تر بود. میانگین تعداد شاخه در بوته با کاربرد تیمارهای آزمایشی ۳۷ درصد بیش‌تر از شاهد آلوده به علف‌های هرز بود. بیش‌ترین عملکرد بیولوژیک نخود در تاریخ کاشت اول و دوم به‌ترتیب با اجرای کولتیواتور (۷۶۰ گرم در مترمربع) و کاربرد پندی‌متالین (۷۴۹ گرم در مترمربع) به‌دست آمد. در تاریخ کاشت اول، عملکرد دانه در کاربرد پندی‌متالین ۸۲/۵ درصد و میانگین آن در کاربرد لینورون و کولتیواتور ۸۶/۴ درصد و در تاریخ کاشت دوم میانگین عملکرد دانه در سه تیمار یادشده ۷۳/٦ درصد بیش‌تر از شاهد آلوده به علف‌های هرز بود. به‌طورکلی، کاربرد علف‌کش لینورون به‌صورت IBS و عملیات کولتیواتور مناسب‌ترین تیمارها در هر دو تاریخ کاشت از نظر کنترل علف‌های هرز در مراحل اولیه شناخته شدند.

واژگان کلیدي: اختلاط هم‌زمان باکاشت، پندی‌متالین، تاریخ‌کاشت، کولتیواتور، لینورون

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